

OPERATION HARDTACK

Project 4.3

Effect of Light From Very-Low-Yield Nuclear Detonations on Vision (Dazzle) of Combat Personnel

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Headquarters Field Command
Defense Atomic Support Agency
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FOREWORD

This report has had classified material removed in order to make the information available on an unclassified, open publication basis, to any interested parties. This effort to declassify this report has been accomplished specifically to support the Department of Defense Nuclear Test Personnel Review (NTPR) Program. The objective is to facilitate studies of the low levels of radiation received by some individuals during the atmospheric nuclear test program by making as much information as possible available to all interested parties.

The material which has been deleted is all currently classified as Restricted Data or Formerly Restricted Data under the provision of the Atomic Energy Act of 1954, (as amended) or is National Security Information.

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It is the belief of the individuals who have participated in preparing this report by deleting the classified material and of the Defense Nuclear Agency that the report accurately portrays the contents of the original and that the deleted material is of little or no significance to studies into the amounts or types of radiation received by any individuals during the atmospheric nuclear test program.

FOREWORD

This report presents the final results of one of the projects participating in the military-effect programs of Operation Hardtack. Overall information about this and the other military-effect projects can be obtained from WT-1660, the "Summary Report of the Commander, Task Unit 3." This technical summary includes: (1) tables listing each detonation with its yield, type, environment, meteorological conditions, etc.; (2) maps showing shot locations; (3) discussions of results by programs; (4) summaries of objectives, procedures, results, etc., for all projects; and (5) a listing of project reports for the military-effect programs.

ABSTRACT

The general objective of this project was to evaluate the dazzle effect on unprotected combat personnel at a minimum safe distance from Shot Hamilton, a fractional-kiloton nuclear detonation.

The experimental procedure required personnel of three test groups (who were oriented at 90, 135 and 180 degrees away from ground zero at a distance of 5,700 feet) to determine and record visual acuity immediately following the shot and, in rapid sequence, determine and record form and color perception of test objects at successively greater distances from the groups. The results showed no significant degradation of vision from dazzle under the conditions of this study.

From review and analysis of previous studies of dazzle and dark adaptation it is concluded that loss of combat effectiveness as a consequence of dazzle will not constitute a major hazard for combat personnel.

PREFACE

The primary purpose of this project was to obtain information on the dazzle effect that would be useful in developing operational guidance for tactical commanders. A bonus objective was to provide the group of officers participating in this project the opportunity of witnessing the firing of this prototype warhead

The Project Officer desires to express appreciation to Major General Leonard D. Heaton, The Surgeon General, formerly Commanding General, Walter Reed Army Medical Center, for making available the services of Colonel Austin Lowrey who acted in the capacity of ophthalmological consultant for the project.

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Chapter I

INTRODUCTION

1.1 OBJECTIVES

The project objective was to evaluate the dazzle effect on front-line combat troops, with specific objectives to determine the degree of dazzle to unprotected personnel at minimum safe distance from ground zero, and the duration of the dazzle effect before combat personnel could again become effective.

1.2 BACKGROUND

1.2.1 General. The dazzle effect, the after image, and the retinal burn constitute the major effects on the eye from the thermal and light portion of the energy spectrum of the nuclear detonation (see Table 1.1 for definitions).

Dazzle is that condition in which the vision is confused by an excess of, or over-powered by, light. It may be caused by the irregular dispersion of light, particularly unpolarized light reflected from the ground or other surfaces or from clouds. The extent of dazzle is determined primarily by the intensity of the illumination impinging upon the eye and is not directly dependent upon orientation with respect to the light source.

The formation of the after image, on the other hand, depends upon orientation since the image of the luminous source must fall upon some part of the retina in order for a scotoma to occur. After images occur following excessive retinal stimulation and are due to extreme bleaching of the retinal photochemical elements. Time, distance, color, and luminosity are factors in the production of after images. The after image primarily involves the central portion of the retina and may last from a few seconds to several hours following the viewing of a nuclear detonation. Retinal burns and scar formation are not part of the uncomplicated case of after image formation.

The term flash blindness has been employed to describe both phenomena, dazzle, and after-image formation. Since flash blindness has the connotation of both permanence (which does not exist in either situation) and the formation of a disabling scotoma, the adoption of this term has led to a general misunderstanding of the nature and extent of the loss of effectiveness which might follow exposure of the eyes to a nuclear flash. For the military, the connotation of blindness has been particularly unfortunate insofar as the factor of morale is concerned.

The term dazzle has received increasing acceptance as a synonym for both the true dazzle effect and after image formation. While this term may be subject to criticism for perpetuating the same type of ambiguity as was implied by the use of flash blindness, it has the advantage of more adequately describing the phenomenon with the greater probability of occurrence and lessening the anxiety occasioned by the use of the term flash blindness.

Retinal burns are caused by the focusing of visible and infrared radiation upon the retina at such levels of irradiance as to cause tissue destruction. Pupil diameter, distance, and atmospheric attenuation are factors influencing the size and severity of retinal burns. These burns can result in permanent damage to the eye terminating in scar formation and possible loss of, or decrease in, visual acuity in that portion of the retina upon which the fireball was focused.

The occurrence of retinal burns at distances of many miles from the point of detonation depends upon the fact that while the radius of the image of the fireball upon the retina varies inversely with distance, the energy per unit area distributed on the retina will be constant, except for attenuation by the atmosphere and the ocular media. While

TABLE 1.1 DEFINITIONS

After image. A visual impression lasting after the image proper has ceased to exist.

Blink reflex. Reflex response of the eyelids to a sudden flash of light resulting in closure of the lids. On the average this reflex requires 100 milliseconds to completion.

Fundus. The portion of the interior of the eyeball around the posterior pole. The part exposed to view through the ophthalmoscope.

Luminance. The characteristic property of an object or an area which makes it appear brighter or darker to the eye.

Mesopic vision. Vision using both rods and cones.

Millilambert. Unit of luminance. One lambert equals $1/\pi$ candle/cm².

Nit. Unit of luminance, equivalent to 1 candle/m²; or 0.0929 candle/ft².

Photon. Unit of intensity of light at the retina. The illumination received per square millimeter of pupillary area from a surface having a brightness of 0.1 millilambert.

Photopic vision. Central vision which functions when light intensity is equal to or greater than that of moonlight.

Scotoma. A blind or partially blind area in the visual field which may be temporary or permanent.

Scotopic vision. Peripheral night vision which functions when light intensity is less than that of moonlight. The central portion of the retina cannot function at this light intensity.

Troland. Equal to $10/\pi \times \text{pupil area (mm}^2) \times \text{luminance (millilamberts)}$.

the inverse square law causes irradiance to drop sharply with distance the square of the radius of the image decreases proportionately with the square of the irradiance.

An extensive study of retinal burns in Northern Europe resulting from viewing solar eclipses with the eyes unshielded showed that the extent of retinal detachment and the residual effects of scar formation have been over-emphasized. After the passage of a number of years there was a minimum amount of loss of vision and it was difficult to visualize the burn sites (Reference 1). Of the cases of retinal burns which have occurred at past nuclear tests, all had minimal residual visual defects with one exception where the image of the fireball was centered directly over the macular area.

Under the conditions of the test reported in this paper, orientation of the groups of subjects was such as to preclude the formation of a retinal image. There was, therefore, no possibility of either a temporary after image or a more permanent retinal burn occurring.

This report deals solely with the dazzle effect except for such portions of the background material which necessarily also include data on the after image and the retinal burn.

The majority of the ophthalmological studies conducted during past nuclear tests were designed to obtain specific information on the performance of filters, shutters, and goggles as well as to evaluate the effect of various types of lighting conditions on instrument reading and other specialized tasks of primary interest to aircrews.

The data obtained by these studies does not lend itself to ready extrapolation to the specific conditions with which the ground forces are primarily concerned, the ability of the combat soldier to recover from dazzle and continue to operate effectively in a tactical role. The airman is placing increased reliance upon central vision in the performance of his operational tasks. As a consequence, the problem of dazzle, for him, can be defeated quite readily by the application of the principle of increased illumination of instruments or other operating gear. The task of the infantryman, on the other hand, involves placing primary reliance upon the peripheral visual fields in the detection of form and movement in the dark or near-dark when engaged in combat at night. This is a difference not only in degree but also in kind which cannot be resolved by the general application of the principles learned at past tests.

These studies did, however, indicate that troops in a daytime environment would not be adversely affected by glare and that the duration of the dazzle effect at night when individuals are fully dark-adapted can be measured in minutes rather than in hours.

1.2.2 Data from Nuclear Detonations. The Ophthalmological Survey Group which studied the Hiroshima and Nagasaki casualties investigated the impairment of visual acuity following those two detonations. No case of flash blindness lasting for more than about 5 minutes was reported among the survivors. In one group of 1,000 individuals within 2,000 yards of ground zero, no lesions were found in the fundus that were believed to be directly related to the flash of the nuclear detonation. In those cases in which impairment of vision was reported, the survey data does not permit of analysis on the basis of distance from or orientation toward the detonation point.

At Operation Buster (Reference 2), a group of individuals positioned in an aircraft orbiting at 15,000 feet, 9 miles from ground zero, looked directly at the flash and then read test charts to check visual acuity. Unprotected test subjects suffered temporarily impaired vision ranging from less than 20/400 to essentially normal vision immediately after the flash; however, all recovered within 2 minutes. Other subjects in the aircraft facing 180 degrees away from the flash experienced no visual impairment. It was concluded that, generally, light-adapted subjects were not seriously handicapped by the nuclear flash at the distance at which they were exposed.

At Operation Snapper (Reference 3), dark-adapted individuals in a light-tight trailer located 10 miles from ground zero and oriented directly toward the burst observed the flash either through red filters or, alternately, with the eyes unprotected. The red lens was selected in order to filter out the high short-wave content of the early part of the bomb spectrum and to permit reading of red-lighted instruments while using the filters. Unprotected subjects regained good mesopic vision in approximately

132 seconds, while those wearing filters required 111 seconds to regain the same degree of vision. The ability to distinguish form at 0.001 ft-candle of illumination (approximately that of moonlight) was regained in 310 seconds for unprotected individuals and 245 seconds for those wearing filters. When threshold illumination was reduced to 0.00001 ft-candle (clear starlit night) an average of 671 seconds was required for unprotected subjects to regain form vision. Immediately after exposure, subjects described a large white or yellow-white absolute scotoma. This was irregular in shape and from 15 to 25 degrees in size. Within 30 seconds the scotoma had decreased in size to 4 to 6 degrees in area. The density of the scotoma became progressively less with decreasing size and at the end of 6 minutes most observers had difficulty in outlining the involved area. Each of the two shots at which subjects were exposed were of approximately 14-kt yield.

During Operation Upshot-Knothole (Reference 4), groups of subjects were exposed to a total of four shots ranging in yield from 16 to 51 kt at distances which varied from 7 to 14 miles. All subjects were dark-adapted and oriented toward the fireball. Protection was afforded by combined infrared absorbing and red transmitting filters, chosen to filter out a large portion of the visible and infrared spectrum while permitting reading of red-lighted instruments. Irradiance was reduced to 20 to 25 percent of the total incident upon the eye by the use of the filters. Reasonably good mesopic vision (20/40) returned in approximately 154 seconds under conditions of 1.57 candle/m² illumination. When threshold illumination approximated that of a moonless night sky, less than 0.001 candle/m², perception of form was regained in an average of 2 minutes 40 seconds. Reducing threshold luminance to that of a moonless, overcast night sky, the ability to distinguish form was regained on an average of 4 minutes. These experiments were devised to obtain an estimate of the usefulness of a specific filter combination in dazzle protection. They were not intended to obtain basic data on dazzle effects and cannot be so interpreted.

At Operation Plumbbob (Reference 5), subjects were exposed behind shutters to determine the extent of protection afforded by use of rapidly operating electromechanical shutters. Aircraft and ground stations were employed. Two individuals exposed without other protection behind a sandblasted aircraft window at a distance of 32,000 yards showed average recovery times of 90 seconds for 0.1 acuity (yield 74 kt). One subject was exposed to an 18-kt detonation at a ground distance of 18,000 yards. A sandblasted diffusing window was again used. Visual acuity returned in 20 seconds.

When the translucent glass plate was employed as a secondary light source with the eyes unprotected, it was found that vision was more acutely affected than was the case when the eye was exposed to direct radiation. Recovery time to partial vision was shorter when the light source was viewed directly (viewing around or through the after image), but the possibility of permanent damage was present. When the flash was viewed through a secondary source, the possibility of permanent damage was virtually non-existent because of the lack of image formation, but the glare effect was all-encompassing, and vision was completely impaired for a period of time.

One eye was unprotected, although the observer was wearing standard Crookes glasses. The subject was so situated with reference to the burst that the line of vision was at about 25 degrees to the periphery of the unprotected eye. It was impossible to see out of the test eye for a period of

just over 2 minutes following the burst, when the peripheral vision started to return. The eye was usable after 5 minutes, although the after image persisted for 12 hours. Other conditions under which the test was conducted were not stated in the report.

As a consequence of the admittedly incomplete results of these studies, there has developed a wide divergence of opinion as to the loss of personnel effectiveness to be anticipated from the dazzle effect. This opinion varies from the denial of any hazard to the view that troops within 5 miles of a detonation will suffer complete loss of night vision for a period of several hours regardless of orientation with respect to burst point. It has been stated that the intense illumination produced at night by

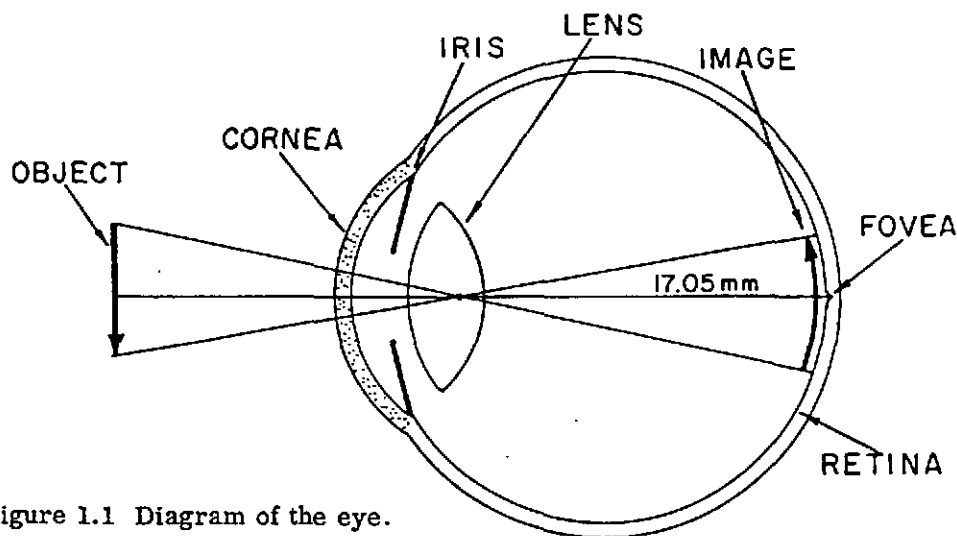


Figure 1.1 Diagram of the eye.

the nuclear detonation inevitably abolishes dark adaptation for considerable periods leading to confusion and disaster in critical situations (Reference 7).

1.3 THEORY

1.3.1 Vision. Vision is a combination of physical, chemical, and psychological processes initiated by light stimuli.

The eye is nearly spherical in shape with an anteroposterior diameter of approximately 24 mm. Light entering the eye passes from front to rear through the cornea, the pupillary opening of the iris, and the lens. The image is then focused on the retina, the light-sensitive inner surface of the eyeball (Figure 1.1).

The cornea is a tough, transparent membrane which, due to its structure, plays a major role in the refraction of light entering the eye. The pupil automatically regulates the amount of light entering the eye by contracting when brightness increases and dilating with decreased illumination.

The lens focuses the image on the retina. Considered as a pure optical system the eye has a focal length of 17.05 mm, from which the image size on the retina can be derived by the formula:

$$i = 17.05 \times o/d$$

Where: i = image size in mm

o = object size

d = distance of the object from the nodal point of the eye

The retina contains a layer of visual cells, the rods and cones, highly specialized minute receptors of radiation in the visible spectrum, which convert radiant energy into nerve impulses. Where the visual axis intersects the retina there is a small pit, the fovea, variously estimated at 0.25 to 0.44 mm in diameter, which is the area of most acute vision. When one looks at an object the eye always rotates so that the image falls upon the fovea and the optical system focuses the image upon the retina at this point. Surrounding the fovea is a yellow-colored oval area, the macula, about 1 mm in the vertical axis and 3 mm in the horizontal plane, made up primarily of cones. Sensitivity of vision decreases as the image of the object is projected upon retinal areas at increasing distances from the fovea (Reference 8).

Although the pupil contributes to the process of light and dark adaptation by regulating the amount of light which enters the eye, and hence the illumination of the retina, the range of pupillary diameter is from 8 mm at full dilatation to 2 mm completely constricted, a variation in area representing only a factor of 16 over a range of brightness of 10^5 . This is in contrast to the sensitivity of the retina which encompasses a range of about 10^{12} , full dark adaptation occurring at 10^{-6} mL and full light adaptation occurring at something over 10^6 mL (Reference 9).

In a study of pupillary constriction involving the dark-adapted eye exposed to short (3-second) intense flashes of light it was shown that constriction was complete in a time interval under 5 seconds, approximating 3 seconds on the average (Figure 1.2). While the initial slope of the curve representing the decrease in pupil diameter was nearly vertical, there was little appreciable change in size during the first 100 msec. Return to the condition of full dilatation was not as rapid, although the study showed that when the dark-adapted pupil was made to constrict by exposure to a flash of light it would return to its original size within 1 minute following cessation of the exposure (Reference 10).

The fovea, composed solely of cones, is the area of the highest state of efficiency of photopic vision. The cones are active in bright light, being stimulated only by higher levels of light intensity. In ordinary illumination visual acuity is 20 times greater at the fovea than in any outlying portion of the retina. This results from the fact that the cones each possess an individual nerve fiber in contrast to the situation in the peripheral portion of the retina where a single nerve fiber is shared by a number of rods. While the fovea is completely rod-free, the macula immediately surrounding the fovea is nearly so. From the foveal margin to the periphery of the retina the cones diminish progressively while the rods increase proportionately. There is some evidence to show that the rods actually increase absolutely to about 20 degrees from the fovea and then begin to decrease in numbers to the peripheral retina. Cones are entirely absent in the extreme periphery (Reference 11).

In twilight vision the fovea is almost completely blind, vision then becoming a function of the rods and the peripheral retina. As the rods are capable of colorless sensations only, color sense is a cone function. A colored object at low illumination, near the threshold of the rods, appears first as colorless. As illumination of the object increases, color is perceived when the threshold of the cones is reached. The cone-free peripheral retina is devoid of color sense (Figure 1.3).

The peripheral retina is a specially differentiated organ for the perception of movement, being much more sensitive in this respect than the fovea. Movement is the most primitive of all visual functions. It is the last to fail in disease and the first to return with improvement of vision. An observer may respond to visually presented movement with only the most vague apprehension of the size, contours or color of the moving object (References 8, 12).

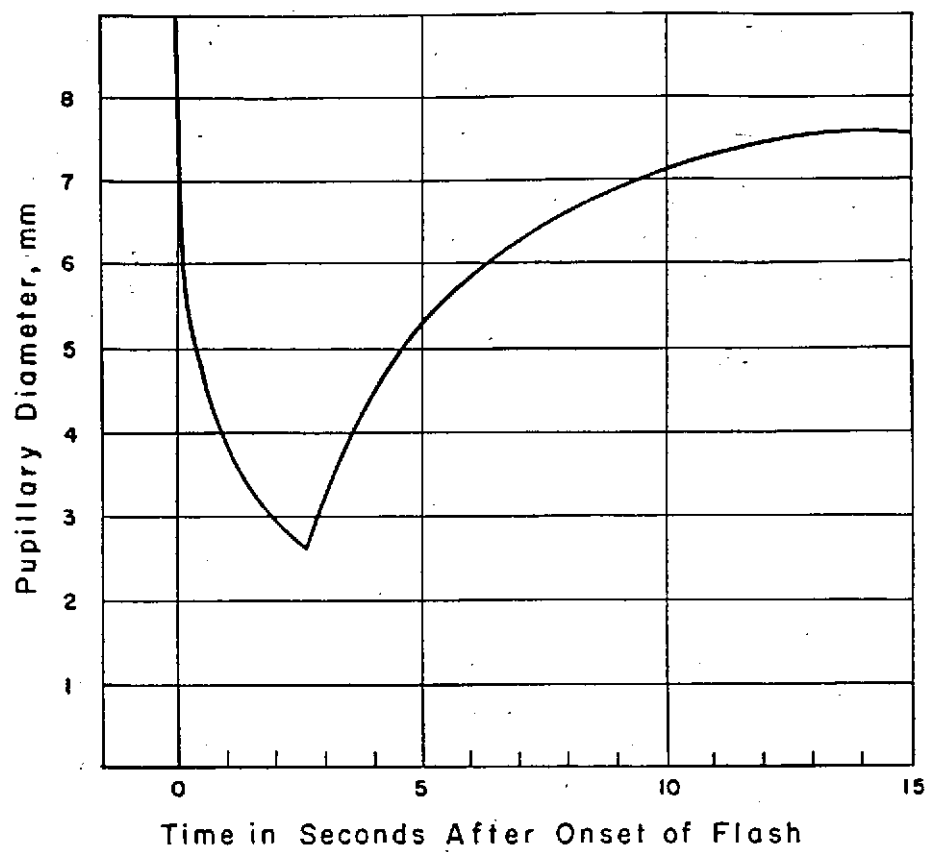


Figure 1.2 Pupillary response to intense light.
Response to 3 second exposure to 147,000 Trolands.

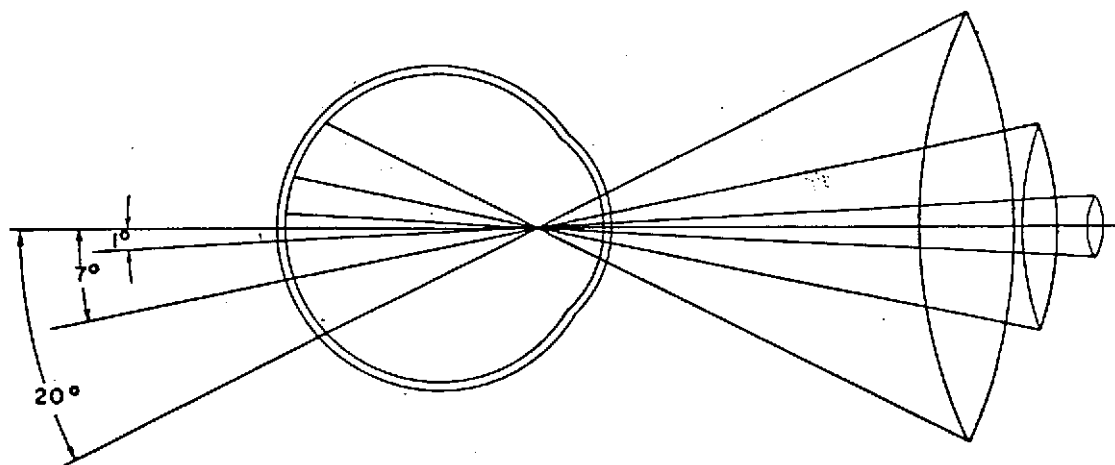


Figure 1.3 The eye in night vision.

1.3.2 Light Transmission. The retina is stimulated by radiation in the narrow range from 400 $m\mu$ to 780 $m\mu$. The visual purple of the rods follows Draper's Law which states that chemical change is produced in a photosensitive substance only by those waves which are absorbed. While the cornea transmits radiation in the range from 297 $m\mu$ to 2,500 $m\mu$, this is degraded by the lens which passes light only in the range from 300 $m\mu$ to 1,300 $m\mu$. The limit of sensitivity of the retina to the longer wave lengths then appears to be at 780 $m\mu$ as the ocular media will transmit much longer rays than this.

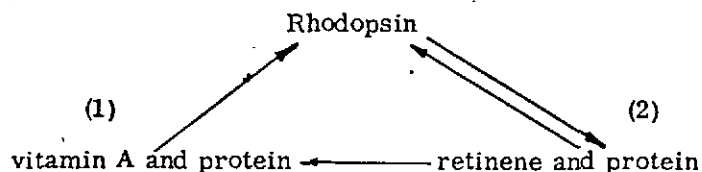
At the ultraviolet end of the spectrum the limit of transmissibility of the eye is near 300 $m\mu$. Most of the waves below 400 $m\mu$ are absorbed by the lens which converts the shorter waves to longer ones which can reach the retina. Wave lengths in the range of 350 $m\mu$ to 400 $m\mu$ cause fluorescence in the lens as the energy of the incident radiations is transferred to particles of the substance absorbing them, in this case the lens, and perhaps the ocular media. These particles act as independent light sources, emitting waves which are for the most part longer than the original radiation (Reference 8).

1.3.3 Dark Adaptation. The photochemical nature of light reception by the rods and cones has been widely demonstrated. The macula owes its color to the yellow pigment contained in the cones, iodopsin, while the rods, more darkly pigmented, contain visual purple, rhodopsin. The presence of rhodopsin is essential for vision in dim light, the sensitivity of the rods depending entirely upon this photochemical substance.

Rhodopsin is bleached by strong light to a lower, steady-state concentration and, re-formed in the dark, restored to maximum concentration. The process of decomposition and regeneration go on simultaneously, so that under steady illumination equilibrium is attained, the number of photosensitive elements remaining statistically constant. As illumination increases, the rate of breakdown is increased so new equilibrium is gradually reached with fewer effective photoactive molecules and therefore lower sensitivity; the eye has become light-adapted. Conversely, weaker light permits regeneration to catch up on the degenerative processes, bringing about dark adaptation, increased sensitivity to dim light (References 13, 14).

Light and dark adaptation are relative terms. When one goes from a lighted room into bright sunlight one shortly becomes light-adapted. Going from the same room into a dark closet results in dark adaptation. Dark adaptation is lost when the eyes are exposed to light of a greater intensity than that to which they were adapted. Recovery of dark adaptation depends critically upon the level of illumination of the area or object being viewed (Reference 15).

The bleaching of rhodopsin is a complex process, initiated by a light reaction followed by a chemical change. Rhodopsin breaks down during bleaching into a protein and an orange-yellow carotenoid pigment, retinene. The regeneration of rhodopsin may proceed in either of two ways, rapidly, from retinene, or slowly, from vitamin A.



The completely dark-adapted retina contains a maximum concentration of rhodopsin. Exposure of the dark-adapted eye to a short intense flash of light should convert a

relatively large quantity of rhodopsin to retinene, but little retinene should have time to go to vitamin A. Following bleaching, rhodopsin regeneration in the rods is negligible for several minutes, during which time dark adaptation is primarily the result of regeneration of iodopsin in the cones. From a consideration of the kinetics of the reactions diagrammed above it appears that dark adaptation following a short intense flash depends chiefly upon Reaction 2 and should be rapid. Long illumination of the eye should bring the cycle to a steady state with dark adaptation depending primarily upon Reaction 1. Adaptation in the latter case should be relatively slow (References 13, 16, 17, 18).

Another concept is that the retina obeys the Bunsen-Roscoe Law formulated for photochemical processes in general. This law states that for the production of a given photochemical effect a constant quantity of energy is required which can be distributed within certain limits by varying either the illumination or its duration. The product of illumination and exposure time is a constant. This law may be stated by the use of an equation of the general form:

$$\text{energy} = k I T.$$

Either increasing the intensity of illumination or lengthening exposure time reduces rod dark adaptation. Provided the degree of dark adaptation is the same in both instances, adaptation after a brief exposure to bright light is the same as that which follows long exposure to dim light.

While the Bunsen-Roscoe reciprocity law applies over a wide range there is evidence that adaptation after short exposures to intense illumination is much more rapid than is the case after less intense long duration exposures. If the latter view can be accepted, extrapolation from laboratory experimentation at necessarily relatively low levels of illumination indicates that conditions following a nuclear detonation are not the most rigorous that can be achieved insofar as dark adaptation is concerned (References 18, 19, 20).

Depending upon the brightness of the field of vision and previous exposure to light, the eye exists either in a light-adapted or a dark-adapted state. The light-adapted eye employs only foveal (photopic) vision which depends entirely upon cone response. As illumination is decreased, the changeover from cone to rod (scotopic) vision occurs at about 0.01 mL illumination with the actual transition from one type of vision to the other occurring in the range of 0.1 mL to 0.001 mL. Although the rods take over from the cones as the intensity of the light is reduced below the cone threshold, the rods do not entirely cease to function if the illumination is raised to a higher level where the cones become active. Within a certain range both types of receptors respond (mesopic vision), but as the intensity of the light is further increased the rods cease to function. In the light-adapted eye, visual purple is bleached to such an extent that the rods become inactive and vision is mediated only through the cones (Reference 21).

Dark adaptation of the cones, and hence the fovea, does occur although it is of minor degree. In the fully dark-adapted eye the sensitivity of the fovea is about 1/1000 that of the extra foveal retina, while the light sensitivity of the peripheral retina is increased by from 10,000 to 50,000 times by dark adaptation.

The course of dark adaptation typically proceeds through two steps. Cone dark adaptation covers an intensity range of about 100 to 1, and is rapid, being complete in about 3 minutes. Rod dark adaptation is more extensive covering a range of 10,000 to 1, and is slow, being complete only after 30 minutes.

Following light adaptation at high intensities of illumination, the threshold for dark adaptation falls in a two step sequence, although the portion mediated by the rods is

delayed after preadaptation to intense light. Conversely, rod dark adaptation begins without delay following preadaptation at low illuminance. Decreasing the intensity of light adaptation diminishes the extent of the first portion of the curve and shortens the time at which the transition from cone to rod function occurs (Figure 1.4). Simi-

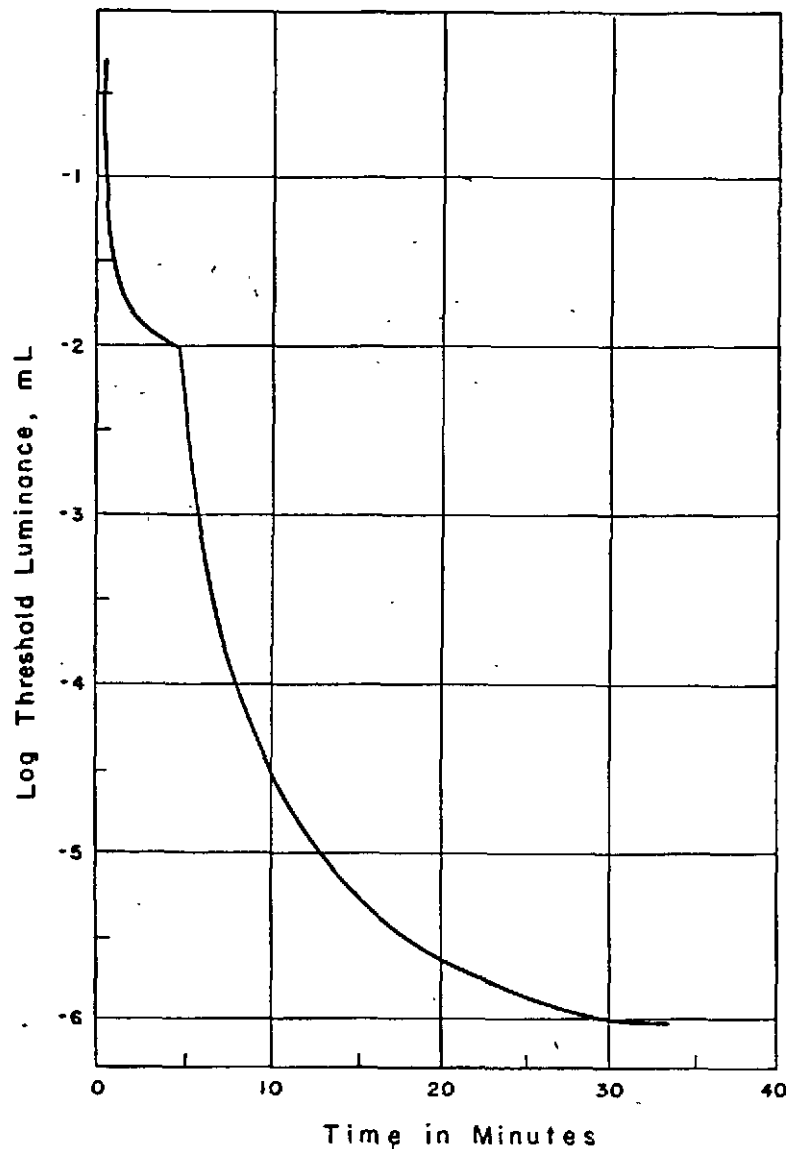


Figure 1.4 Idealized curve for dark adaptation.

larly, with short exposures at low light adaptation only the portion of the curve representing secondary rod dark adaptation appears (References 22, 23).

In the early stages of dark adaptation there is a precipitous drop in threshold illuminance with the curve for adaptation gradually lengthening as complete adaptation at low levels of illumination is approached (Figure 1.4).

When the eye is adapted to a certain brightness and is then suddenly exposed to a much greater brightness the latter is called glaring if it is uncomfortable. This is a highly subjective criterion which depends variably upon the individual. Some individuals can tolerate a greater degree of brightness without discomfort than others; psychological

and physiological factors which cannot be equated enter into the problem when defining glare. The dark-adapted eye is dazzled by even moderately bright light but adaptation to the higher illumination develops rapidly. During light adaptation the pupil constricts, the rhodopsin is bleached, and the sensitivity of the retina decreases. The greatest decrease in retinal sensitivity occurs during the first 20 to 30 seconds followed by a more gradual fall for a period of approximately 10 minutes. At the end of this time light adaptation is complete for all practical purposes (References 8, 24).

1.3.4 Dazzle. It appears that there is a direct relationship between the intensity of the illumination to which the eye is light-adapted and the time required to reach a given threshold during dark adaptation. The higher the illumination the longer the eye requires to dark adapt.

In one series of experiments it was shown that when the eye was exposed to light for 2 minutes and then tested for dark adaptation, a period of 18 to 22 minutes was required for the eye to completely adapt to a level of 10^{-3} mL after exposure to 400,000 photons preadaptation intensity. At 40,000 photons, 14 to 16 minutes were required, and at 4,000 photons only 7 to 9 minutes.

Similarly, where subjects were tested at preadapting luminances varying from 1 to 10,000 mL there was a direct relationship between preadapting intensity and time required to reach a given threshold, again at approximately 10^{-3} mL. The time ranged from 30 minutes at the highest preadaptation intensity to essentially instantaneous dark adaptation at the lowest. In this experiment the duration of the flash was 0.04 second.

The dark-adaptation curves obtained in three separate experiments are presented in Figure 1.5 to show the similarity of these curves under markedly different experimental conditions.

While it has been demonstrated that, for a given intensity of preadaptation, shortening the exposure time results in more rapid dark adaptation, or conversely, holding the time of preadaptation constant and decreasing the intensity of the preadapting illumination increases the speed of dark adaptation, the majority of these studies have been made either with low preadapting intensities or long time intervals as compared with the conditions existing following a nuclear detonation. In spite of these shortcomings some pertinent conclusions regarding the course of dark adaptation can be drawn from the existing data. It should be noted that even with intensities of 10,000 mL preadaptation illumination the course of dark adaptation is not markedly different from the idealized curve of Figure 1.4 (References 25, 26, 27, 28).

The net effect of increased dazzle is to cause a less precipitous drop in the curve for dark adaptation; the decrease in threshold illuminance is at a more gradual rate. The general form of the luminance threshold curve is not appreciably altered with the exception that the decline to baseline is more gradual than is the case under ordinary illumination.

From Figure 1.5 it is noted that the definite cone-rod break in the adaptation curve does not appear when preadapting luminance is on the order of 100 mL or lower. In spite of experimental evidence that the duration of preadaptation to 3,000 Lux must exceed 2 minutes in order for cone dark adaptation to occur, only the portion of the curve representing rod dark adaptation being evident after 1-minute exposure at this level, it appears from other studies that high-intensity light even at brief exposure times causes at least some light adaptation of the cones (References 19, 22, 29).

Essentially the situation depends upon the degree of light adaptation which occurs during the 0.1 second period of exposure to the flash of the nuclear device or weapon before the blink reflex terminates the exposure. With the exception of a relatively few

experiments in which preadaptation was induced at time intervals of less than one-quarter second, there exists a marked lack of good evidence bearing upon this point. If the retina is not light-adapted to a significant extent during the period of exposure to the nuclear flash, there is no reason to accept the doctrine that dark adaptation will be grossly delayed after such an exposure. That a certain degree of light adaptation occurs is evident in the light of work previously presented; however, the experimentation

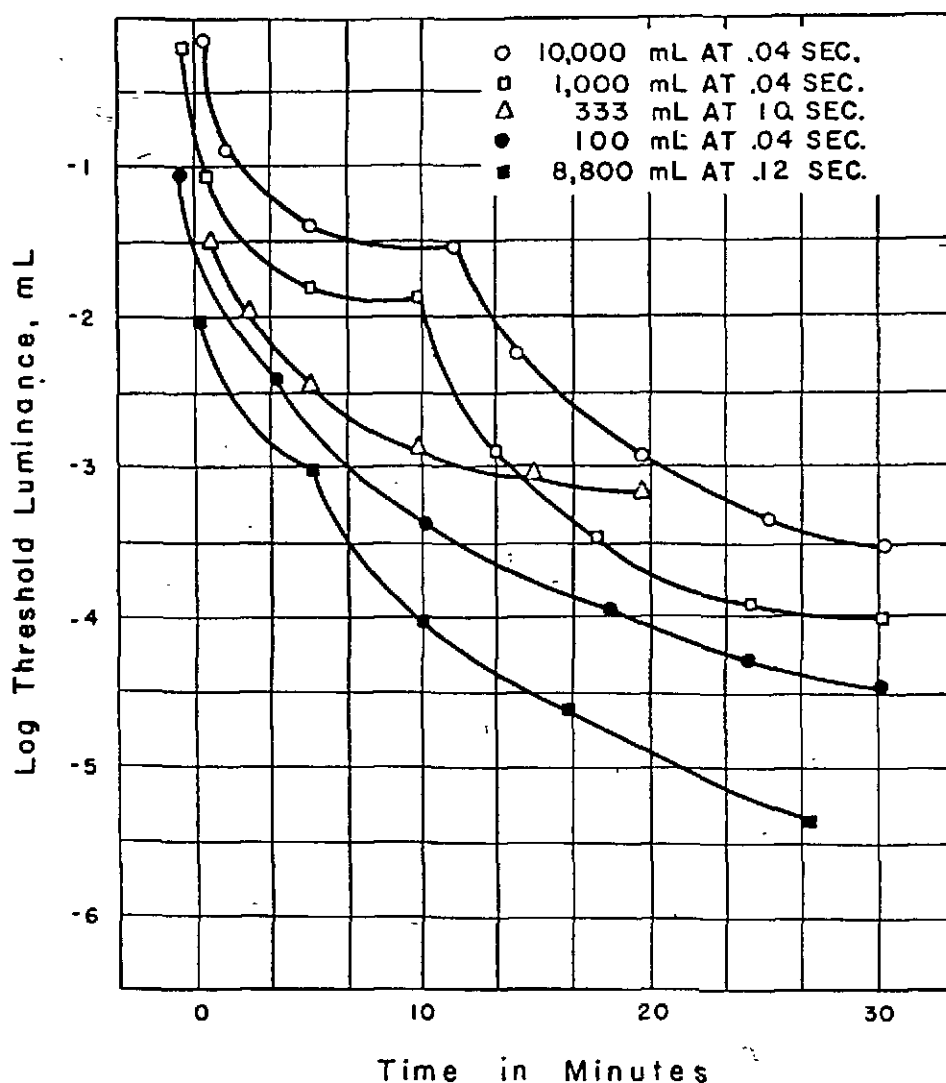


Figure 1.5 Dark adaptation after preadaptation at varied illumination. Preadapting luminances of 10,000, 8,800, 1,000, 333, and 100 mL.

conducted on the Bunsen-Roscoe reciprocity effect suggests that the light adaptation which does occur is not of major extent.

It has been stated by one experimenter that the evidence strongly suggests that the effects of changes of exposure level are not as dramatic or prolonged as might be expected. The mass of publications and documents reviewed in preparation for this paper presents no overwhelming evidence to cause one to take exception to this statement (Reference 30).

1.3.5 Spectral Distribution of Emitted Radiation. In considering the causation of dazzle, major emphasis must be placed upon the factors of changing size, color temperature, and variations in spectral emission of the fireball. The initial part of the thermal pulse, consisting of the first maximum and the first minimum, contains such a small fraction of the total energy that it may be neglected in almost all applications of this phenomenon.

The variation of thermal power emission by the fireball with time to the second maximum indicates a rapid rise followed by a gradual decay of fireball surface temperature. As the temperature changes, the relative amount of emitted energy in each wave length of the spectrum also changes. Measured values of band spectral distribution as a function of time and total thermal energy versus time are available for some shots.

The average color temperature of operational weapons is calculated to be on the order of 5,500 to 6,000 K for air bursts, at peak irradiance. No conclusive statement can be made regarding surface bursts insofar as color temperature is concerned, although it appears that about 3,000 K can be assumed for purposes of calculations of the spectral emittance of such bursts. It appears, further, that the integrated spectral distribution of air bursts prior to atmospheric attenuation can be approximated by the spectral distribution of a black-body emitter of 6,000 K.

For the black body at 6,000 K the distribution of total thermal intensity in six consecutive spectral regions of interest is as follows:

Wave Length	Percent Distribution
220 to 360 $m\mu$	9
360 to 530 $m\mu$	22
530 to 640 $m\mu$	14
640 to 780 $m\mu$	15 (approx)
780 to 950 $m\mu$	12
950 to 2,500 $m\mu$	26

Since the retina responds to radiation in the range of 360 $m\mu$ to 780 $m\mu$ the portion of the spectrum which can affect the retina represents almost exactly one half of the total spectrum (51 percent). Of the remainder, the major portion lies in the infrared region (39 percent), and can be expected to be of consequence from the standpoint of retinal burns. Where dazzle is concerned, there is no evidence to support or deny infrared effects. At 3,000 K the curve is entirely different with virtually no energy in the ultraviolet range, below the threshold for vision. On the order of 22 percent of the total lies in the visible region, 360 $m\mu$ to 780 $m\mu$, while almost 78 percent is in the near infrared and infrared regions. It is apparent that the surface burst should not predispose to dazzle even if the luminous flux were not further degraded by the presence of masses of debris in the fireball (References 31, 32, 33).

Assuming that only that portion of the total radiant energy reaching the eye before the blink reflex occurs is effective in causing dazzle, only the energy impinging upon the eye before 100 msec need be considered. The time at which the maximum radiant power is reached varies with yield. When time to the second maximum is plotted against yield it is seen that at a yield of 10 kt t_{max} becomes greater than 100 msec, hence t_{max} of yields greater than 10 kt will occur after the blink reflex. It can then be assumed that for weapons below 10 kt essentially all the luminous flux in the visible range is effective in causing dazzle. For yields over 10 kt it is necessary to calculate the portion of the total radiant energy which is emitted prior to 100 msec. With larger yields a greater total increment will be emitted in the form of radiant energy prior to

100 msec after burst time, but it appears that the effectiveness of this energy in causing dazzle decreases with yield (Reference 31).

The change in color temperature with time after detonation is also critical to the occurrence of dazzle, particularly where exposure to only a part of the thermal pulse is considered (Figure 1.6). As the color temperature of the fireball rises to t_{\max} proportionately more of the spectral distribution falls within the visible and ultraviolet regions. There is an inverse relationship between color temperature and the peak

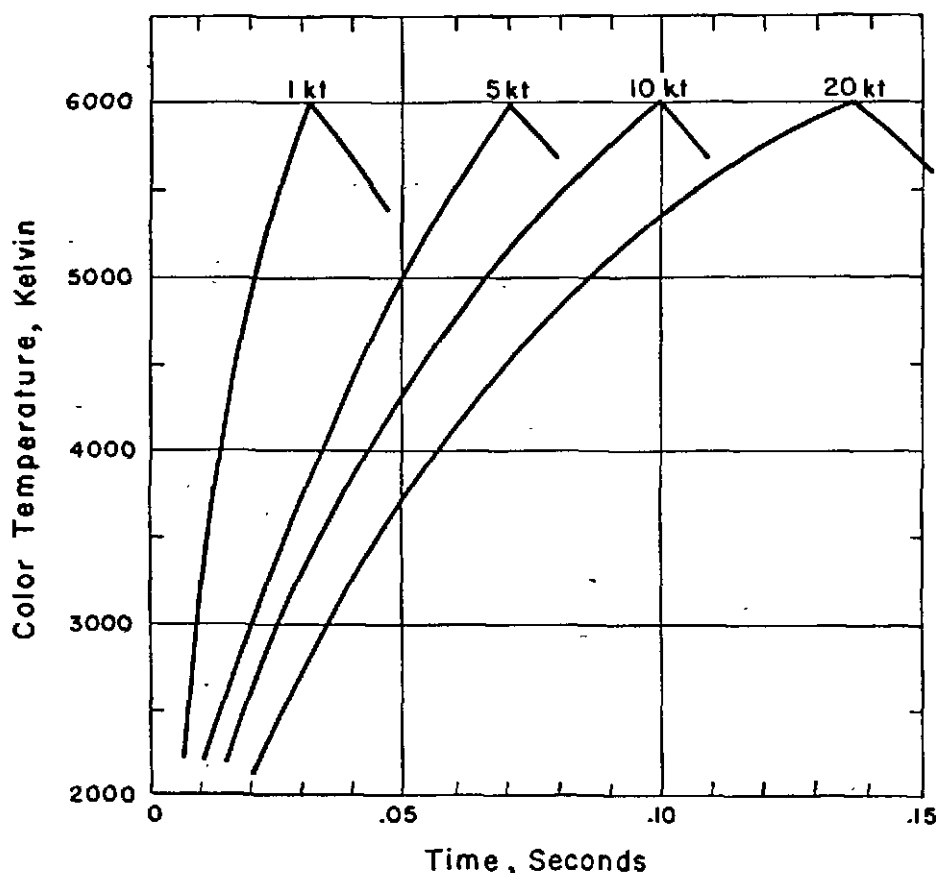


Figure 1.6 Variation in color temperature of fireball with time. The curve for 20 kt is taken from TM 23-200. The remaining curves are intended for comparative purposes.

wave length emitted. At higher temperatures the peak occurs at shorter wave lengths, while at lower temperatures the peak occurs at longer wave lengths. With higher yields, where the blink reflex cuts off exposure prior to t_{\max} , correspondingly smaller portions of the visible spectrum will be absorbed by the retina with the consequent production of dazzle.

1.3.6 Scatter and Attenuation of Radiation. Atmospheric attenuation of the direct beam occurs by absorption and scattering. Energy scattered out of the main beam but incident upon the target as diffuse thermal radiation can equal or even exceed the direct beam radiation. Not all scattered radiation is incident upon the target as some is lost by upward scatter and some by absorption by the ground. That which strikes the retina contributes to dazzle (Reference 30).

Comparison of image sizes for a series of representative yields at various distances shows the relative unimportance of the after image in the loss of visual effectiveness. At the several nuclear detonations where studies of dazzle were conducted image size varied from 0.313 mm to 0.706 mm in diameter depending upon the yield and distance involved (References 2, 3, 4).

It is apparent that the amount of light scattered or reflected by the atmosphere is at least as important in causing dazzle as is the luminous flux striking the eye directly.

In numerous reports there appears the concept that the study of the collimated beam will give meaningful data on adaptation. While this may be true for foveal adaptation it probably does not hold for rod adaptation. The image of the fireball on the retina is the determinant of retinal burns but dazzle is dependent upon all the scattered light which enters the eye as well as the direct rays from the fireball. When the beam is collimated and a limited area of the retina illuminated, the macular area and the immediate peripheral retina in the majority of experiments, data on the foveal response may be obtained. To approximate the condition of the eye at night when fully or almost completely dilated it is necessary for experimental conditions to be such that scattered and reflected rays from all directions enter the eye.

In one laboratory study (Reference 34), subjects were exposed to a photoflash bulb in the forward field of vision with the eyes unprotected. At a distance of 3 feet the bulb gave approximately 16,000 ft-candle lasting on the order of 30 msec. As the color temperature of the bulb was 3,800 K the peak spectral emittance was shifted toward the infrared region. In this respect it did not resemble the flash from an air burst. The bulb subtended an angle of about 3.5 degrees at 3 feet, hence the image almost covered the macula in the vertical dimension although it covered only one third of the horizontal extension of this region.

The subjects were almost completely blinded by the flash for a period of 15 to 20 seconds. There was after-image formation but it was possible to see through the image after about 15 seconds.

To study the effect when the light was not viewed directly, a large white card was placed in the line of vision and 18 inches from the eye with the flashbulb being exploded next to the ear. Each subject experienced a blinding flash covering the entire field of vision with momentary watering and blinking of the eyes, but within 2 to 3 seconds the blinding effect had dissipated and normal vision was restored. When the eyes were dark-adapted, the impact of the flash was greater instantaneously but again the blinding effect disappeared in 2 to 3 seconds. The illumination on the card was calculated to be one half that on the retina when the bulb was viewed directly.

The study concluded that the dazzle resulting from a nominal weapon should have no tactical significance other than resulting in a temporary loss of night vision for a period of 5 to 10 minutes.

Chapter 2

PROCEDURE

2.1 OPERATIONAL PLAN

Participation was planned for Shot Hamilton,

The predicted yield of the device was so low that at the distance required for the safety of the test group, little, if any, significant dazzle was expected; however, negative results were considered to be valuable since they would indicate that in tactical situations, at comparable distances, no coordination with adjacent units would be required insofar as dazzle was concerned.

Thirty-six Army and Marine officers from units, schools, and installations were selected to serve as the test group. Unfortunately, the 3-day delay of Shot Hamilton necessitated the return of eleven officers to home stations. Each participant had been given at his home station, an eye examination which included the determination of accommodation, near and far vision, visual fields, and an examination of the fundus. The accommodation and fundoscopic examinations were repeated upon arrival of the participants at the test site and compared with the previous examinations.

Test-group positions and the test-site layout were as indicated in Figure 2.1. The record form issued to each subject is illustrated in Figure 2.2. A Jaeger (vision) chart used in the test procedure was imprinted upon the reverse of this chart.

At shot time, all personnel, eyes open and unprotected by filters or goggles, were oriented as indicated in Figure 2.1. Immediately after the shot, all subjects determined their visual acuity by reading the Jaeger chart and made an appropriate entry on the record form. This entry consisted of noting on the form the smallest Jaeger line which could be read and the time at which this was determined. A voice count by seconds was given commencing at zero time and continuing for the duration of the test procedure.

Upon command, all subjects then turned to face the target array area and, in so doing briefly observed the forming partly luminous, nuclear cloud. Initially, the target panels and the two individuals manning the target positions were concealed from the subjects. At H + 10 seconds the man at Target Position 1 moved out from the cover of the tank behind which he had been concealed. Each subject was required to determine whether he could identify the figure of a man and, if so, whether he was seen clearly or hazily. This information was recorded by each subject. At H + 15 seconds a blue-on-white panel was displayed at Target Position 1. Each subject was to identify and record the colors and note whether seen clearly or hazily.

The man at Target Position 2 moved out from the concealment of the bunker at H + 25 seconds. Again, each participant determined whether he could identify the figure of a man and, if so, whether clearly or hazily. At H + 30 seconds a red-on-white panel and a green-on-yellow panel were displayed at Target Position 2. Each subject identified and recorded the colors and whether seen clearly or hazily.

At H + 45 seconds the entire group faced directly away from the target array, upon

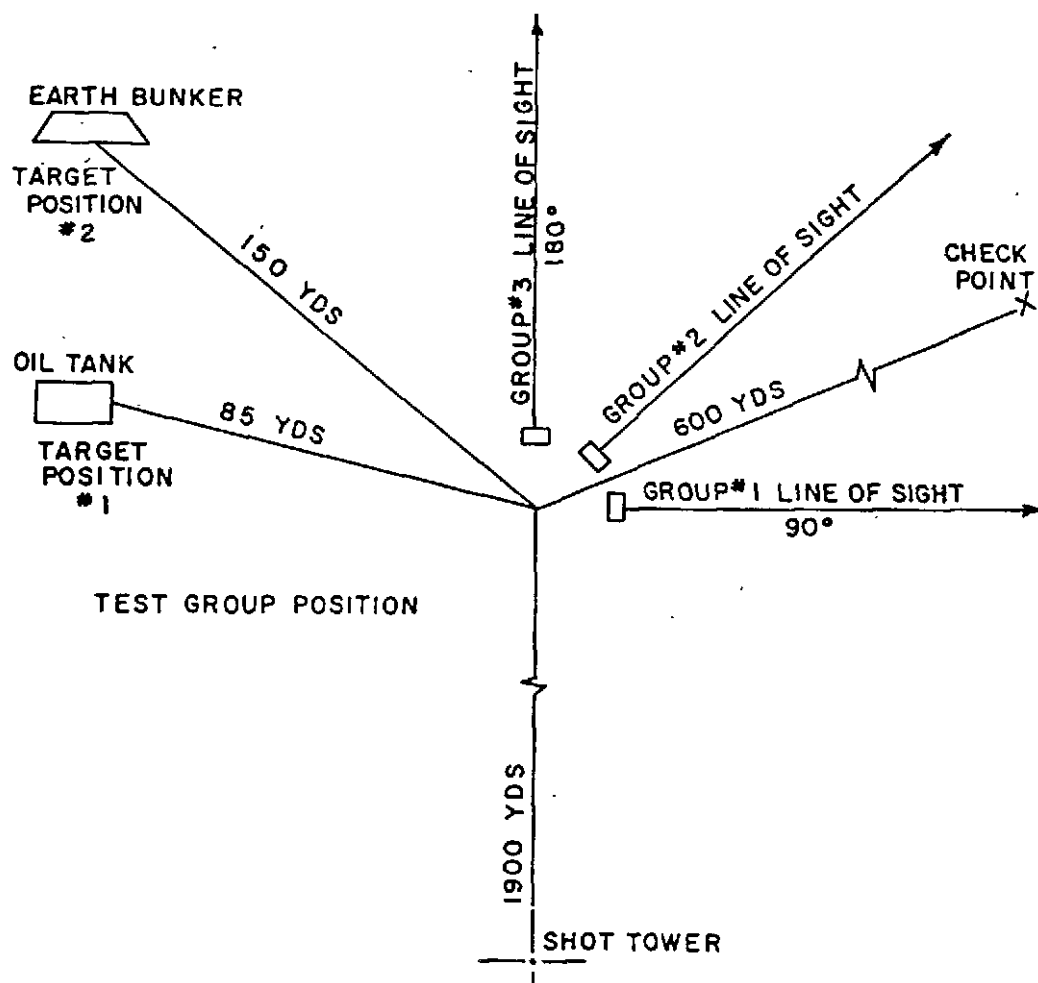


Figure 2.1 Test location layout

NAME _____

ORIENTATION _____

		CLEAR	HAZY	
JAEGER	1			COLOR
	2			
	3			
	4			
MAN	1			
	2			
TARGETS	1			
	2			
	3			
CHECK POINT				
COLORED PANEL REPEAT				

Figure 2.2 Observer record sheet.

command, and were required to identify and record types and colors of vehicles at a check point 600 yards distant.

At H + 60 seconds the test group faced about toward the target array where the men at both Target Positions 1 and 2 reappeared simultaneously and displayed all three colored panels. The subjects were required to determine and record whether they were able to see the men and panels more clearly than at the time of the previous presentations.

At this point the project was formally terminated. All participants then were given an ophthalmological examination which included a visual-acuity and fundoscopic check.

2.2 DATA REQUIREMENTS

The time to recovery of visual acuity was required with an accuracy of + 2 or 3 seconds; good reliability was expected. Data on form, color and clarity of perception at specific times was required; again, good reliability was expected. The method of recording data is illustrated in Figure 2.2.

Chapter 3

RESULTS

3.1 DAZZLE

None of the twenty-five subjects participating in this study reported dazzle from Shot Hamilton. There was no difference in this respect between the three groups, regardless of orientation.

3.2 VISUAL TESTS

Accommodation and near vision were unaffected. Immediately after the shot, all subjects were able to read that portion of the Jaeger test chart corresponding to their

TABLE 3.1 SUMMARY OF OBSERVERS' RECORDS, SHOT HAMILTON

All times expressed in seconds from shot time.

Subject	Time to Recovery, Normal Jaeger	Time of Appearance of First Man	Time of Appearance of First Target	Color, First Target	Time of Appearance of Second Man	Time of Appearance of Second Target	Color, Second Target
90-degree orientation:							
R. H. A.	2	16	16	16	28	28	30
J. D. A.	2	17	17	17	31	31	31
L. D. A.	2	16	16	16	28	28	28
L. E. B.	2	10	15	15	25	30	30
G. D. C.	3	17	17	17	28	28	28
T. H. F.	5	17	17	17	25	31	31
L. E. F.	7	15	25	25	25	35	35
G. W. G.	5	16	16	16	27	27	27
L. W. J.	1	15	15	15	Turned away prematurely.		
P. V. J.	2	Operator for target position No. 1.					
A. L.	2	15	16	19	22	27	31
W. J. McD.	2	Operator for target position No. 2.					
L. E. P.	5	16	17	17	28	31	31
M. L. S.	4	15	15	15	44	44	44
R. H. V.	3	10	15	15	25	30	30
135-degree orientation:							
J. W. A.	2	14	15	15	31	35	36
J. H. B.	3	10	18	18	25	30	30
R. J. McN.	5	12	14	14	Turned away prematurely.		
R. S. P.	1	13	17	17	Vision obscured.		
F. E. S.	5	10	16	16	25	29	29
180-degree orientation:							
J. G. H.	5	16	16	16	30	30	30
R. A. L.	3	15	15	15	30	30	31
A. J. R.	5	10	15	15	25	30	35
M. A. R.	5	15	15	15	27	30	30
J. M. W.	2	10	15	15	25	30	30

normal vision as determined by previous examinations at home stations and at the Nevada Test Site (NTS). The time required to read the test chart varied from 1 to 7 seconds, with the majority of the observers reporting either 2 seconds (9 individuals) or 5 seconds (8 individuals) as the time increment. Table 3.1 summarized the data.

The movement of the two men from their places of concealment at the target stations was detected almost immediately by all observers. The range of times reported for

the appearance of the first individual was from H + 10 to H + 17 seconds, with the majority indicating either H + 10, 15 or 16 seconds. Time of appearance of the second man was reported in the range from H + 22 to H + 44 seconds, with the largest sample at the correct time of H + 25 seconds. All observers reported that both movement and body outline were clearly seen.

The target square at the near target station was displayed at H + 15 seconds and the two targets at the farther station at H + 30 seconds. Observers reported time of display of the first target as occurring at from H + 14 to H + 25 seconds. The second target display was reported at H + 27 to H + 44 seconds. There was a general spread of time intervals reported, but nine individuals recorded the correct time of appearance of the first target, while eight reported correctly on the appearance of the second.

Target colors were described accurately in every case. The color of the near target was distinguished immediately upon its appearance, and the times recorded for color discrimination were identical with time of appearance in virtually every record. Five individuals required from 1 to 5 seconds after the appearance of the farther target display to make the correct color identification.

Visual acuity for distant objects was unaffected. When tested at H + 45 seconds, all observers reported the ability to distinguish movement and outline of people and the color of vehicles at a distance of approximately 600 yards.

At H + 1 minute, the targets were displayed again, and the observers were required to indicate whether they were able to see the outline and colors of the targets more clearly than had been the case of the first display. All individuals reported no change in visual acuity.

3.3 POST-OPERATION EXAMINATIONS

All personnel participating in the test received complete ophthalmological examinations from 15 to 45 days after returning to home stations. Without exception, there were no changes in visual tests or the eyes themselves which could be attributed to participation in this project.

Chapter 4

DISCUSSION

4.1 ACCURACY OF TEST METHODS

The gross techniques employed for data collection were considered adequate for the purpose of meeting the stated objectives of this project. The use of unrefined instrumentation such as the stopwatch and verbal time signals, when combined with the delays inherent in reaction to visual stimuli, admittedly produces relatively unsophisticated data. It was felt, however, that order-of-magnitude figures were sufficient for the purpose of drawing general conclusions as to the nature of the problem which the use of the weaponized version of this device might impose upon tactical operations.

Where variations from the average response time appeared in the check sheets of individual observers, review of the record with the individual invariably showed that the target was lost to view through circumstances unrelated to visual acuity.

4.2 RELIABILITY OF DATA

The general reliability of this data was considered to be quite good. The project personnel included a group of commissioned officers from the several services, the majority of whom had combat service as well as staff experience. By reason of their combined background and experience, it was felt that they were well suited for the collection of the required data, even though the experience of participation in a nuclear test was new to many of them.

The requirement for the gathering of as much data as possible on several different visual tasks forced acceptance of a short time interval between the presentation of the separate problems. It was recognized and accepted that this would cause a wider spread of data than would occur under more ideal circumstances. As was anticipated in this situation, the minor discrepancies in recording time of response were insignificant when viewed in the light of the completely negative data obtained.

However, the method of experimentation would have been equally valid in the event that positive data on the dazzle effect had been developed.

Where response time is not critical, as in the case of larger-yield weapons and longer recovery times, the objection to unsophisticated test techniques can be overcome by repeating test procedures until an adequate response is measured.

4.3 CORRELATION WITH PREVIOUS OPERATIONS

The results of previous experiments on flash blindness and dazzle (References 2, 4), have shown that dazzle is either non-existent or transitory in nature when the individual is light-adapted. Since Shot Hamilton occurred 2-1/2 hours after sunrise, light adaptation of the subjects in this study was complete. It has also been demonstrated that the return of photopic vision was rapid when adequate illumination was provided for the performance of visual tasks.

The results of this project were not at variance with any previous test data.

4.4 TACTICAL SIGNIFICANCE OF DATA

4.4.1 Inadequacies in Prior Test Data. Optimistically, one of the goals of this report was the derivation from test data of a chart or set of graphs from which could be determined the relative probability of dazzle in any group at risk. It was conceived that yield could be plotted against distance for a probability of 0.5 for dazzle in any individual oriented directly toward the burst point. On the basis of existing data it is doubtful whether such a graph could be developed without a disproportionate amount of effort in the light of the questionable validity of the conclusions to be drawn from the data.

Accurate measured values of spectral-band distribution of fireballs for a few yields are available (Reference 35). Measurements of luminous intensity at representative distances are limited. To determine the total luminous flux from existing data on the radiant flux requires a lengthy process of integration at changing wave lengths and varying energies. Finally, the variable psychological values which the concepts of brightness and color evoke in different individuals are difficult to evaluate in objective terms.

Table 4.1, using data from Operation Plumbbob (Reference 5), illustrates the problem of evaluating any given device in terms of its dazzle potential. Although the receiver in this case selectively evaluated the same wave lengths which affect the human retina, the major variations in luminous intensity between the several devices cannot be explained on the basis of distance or burst height. The difference in luminous flux between the Boltzmann and Wilson devices is particularly puzzling inasmuch as the receiver was at essentially the same distance from the burst point in each case and both devices were positioned on 500-foot towers. Variations in design of the devices might have been of significance in causing these perturbations, or there may have been other extrinsic factors which were not apparent in the test reports, including differences in atmospheric transmission and cloud cover reflection.

The comment has been made by several researchers in the thermal field that it is conceivably feasible to determine radii for dazzle as a function of yield, distance, and visibility but that such radii would have little utility and probably would not represent any real situation which would be duplicated under tactical conditions.

4.4.2 Applicability of Prior Test Data. During Operation Snapper (Reference 3), dark adaptation was determined on subjects exposed to two shots each of approximately 14 kt. These results cannot be compared directly with the data from Operation Upshot-Knothole (Reference 4), due to differences in experimental conditions in the two operations. The combined results of these studies are presented in Table 4.2.

At Operation Snapper, unprotected dark-adapted subjects were exposed to bursts in the forward field of vision. At Operation Upshot-Knothole, following the discovery of retinal burns in two subjects at Operation Snapper, dark-adapted subjects were protected by filters which cut out both the ultraviolet and infrared portions of the spectrum. These filters transmitted radiation in a narrow range from 600 m μ to 900m μ , cutting off a considerable portion of the visible spectrum. This combination of filters permitted the passage of from 20 to 25 percent of the incident light.

Although experimental conditions were the same in each case, variations in yield and distance in the four shots of the Upshot-Knothole series mitigated against ready interpretation of the data. The results of these studies are presented as part of Table 4.2. When the inverse square law of illumination is taken into account, it is apparent that the illumination at the retina is relatively the same in both Shots 2 and 5. The

differences in time to form-perception at 0.001 and 0.00001 candle/m² cannot be explained on the basis of the relatively small differences in preadapting luminance.

The average time to perception of form where the target was lighted at approximately the level of moonlight was on the order of 4-³/₄ minutes at Operation Snapper. The

TABLE 4.1 ILLUMINANCE INCIDENT AT SITE

Shot	Approximate Yield	Distance from Ground Zero	Peak Illumination
	kt	yards	lumens/ft ²
Boltzmann	11	17,600	42,238
Wilson	10	15,136	118,666
Diablo	18	18,304	12,100
Priscilla	36	20,649	94,904
Hood	74	32,426	61,271

spread of times ranged from 3 to 6 minutes. These times were entirely comparable to those in the Upshot-Knothole studies where average time to perception of form at the level of a moonless night was about 2-³/₄ minutes with a spread from 1 minute to 4-¹/₂ minutes, although the Upshot-Knothole data was taken at a lower degree of target illumination and allowance must be made for the lesser intensity of preadapting light resulting from the filters used.

The inconsistencies of the data prohibit the derivation of significant curves for adaptation. Recovery of dark adaptation following Shot 7 was more rapid than after

TABLE 4.2 SUMMARY OF APPLICABLE TEST DATA

Shot	Yield, kt	Distance, mi	Image Diameter, min	Time to Perception of Form at Given Threshold Illumination	
Operation Snapper:				10 ⁻³ ft-candle	10 ⁻⁵ ft-candle
—	14	10	0.33	4 min 48 sec	8 min 14 sec
Operation Upshot-Knothole:				10 ⁻³ Nit	10 ⁻⁵ Nit
1	16	7.5	0.47	3 min 18 sec	5 min 17 sec
2	24	11	0.37	2 min 51 sec	4 min 2 sec
5	27	14	0.31	1 min 50 sec	2 min 50 sec
7	51	8	0.70	2 min 10 sec	3 min 39 sec

Shot 1 although the yield of Shot 7 was more than three times that of the first shot while the distance to the subjects was relatively the same in both cases. Only one of the four subjects in Shot 7 had times to recovery which were strictly comparable with the times noted after Shot 1. All the remaining three subjects recovered dark adaptation for the level of target illumination employed in a shorter time than any of the four subjects exposed to the first shot.

With minor exceptions, the spread of data for all shots in both series could be considered as within average physiological and psychological limits for this type of experiment.

Assuming that there is a significant difference in time to form-perception between the two shots, Shots 1 and 7, a possible explanation may be found in the maximum

color temperature attained in each case prior to the operation of the blink reflex. From Figure 1.6, the color temperature of the 16-kt fireball is seen to be virtually at its maximum at the time of the blink reflex, while the theoretical curve for 51 kt meets the reflex time considerably below maximum temperature. While the total energy incident upon the eye favors the higher yield, less of this energy is in the visible range and by analogy less likely to cause dazzle.

Better data on changing color temperatures with time to maximum would permit a more critical evaluation of the contribution of this phenomenon to dazzle.

4.4.3 Dazzle from Low-Yield Weapons. While it appears that weapons below 10 kt in yield will be more likely to produce retinal burns and dazzle than higher yields, there is obviously a lower limit to weapon size which can be included in this category.

If the Bunsen-Roscoe Law holds at these extremely brief periods of time, a knowledge of the luminous intensity delivered by these fractional kiloton warheads at distances of interest should permit the determination of the probability of dazzle in comparison with low-kiloton-yield weapons. Since none of the required data is available, and it is doubtful that absolute reciprocity holds at these time intervals, it can be reasoned intuitively that the product of the intensity and the duration of the fireball in the case of the 20-ton weapon cannot cause dazzle comparable in severity to that from a 1-kt weapon, as an example.

The probability of retinal burns in those oriented directly toward the fireball can be readily determined from a knowledge of the image size and the caloric flux at distances of interest. Although the probability of dazzle cannot be so readily determined, it is reasonable to assume that the limited duration of the flash combined with the low intensity of illumination makes the development of significant dazzle unlikely at distances beyond those at which the nuclear radiation from the weapon is the limiting effect insofar as employment is concerned.

4.4.4 Significance of Dazzle. Prior to writing this report, a general literature search was conducted with the purpose of establishing quantitative standards for the recovery of dark adaptation under the most rigorous possible conditions, the perception of form and movement at absolute minimum illumination following exposure to extremely intense light, comparable to that from a nuclear weapon, in the forward field of vision. This criterion involved the return to baseline conditions of the dark-adaptation curve where the illumination of the test object is approximately that of a moonless, starless, overcast night. It was felt that the calculation of limiting parameters under these extreme conditions would be valuable in assessing the loss of effectiveness in personnel to be anticipated under less rigorous conditions.

Unfortunately, the experimental data, for the most part, did not extend to the levels of interest implicit in this criterion. Data on foveal adaptation was relatively complete and permitted reasonable extrapolation from experimental conditions to those which held in the field. When rod vision is considered, however, there were few data points which were of value.

With few exceptions, in experimental work, the extent of light adaptation attained prior to dark adaptation has been so great and of such long duration that it is doubtful whether any meaningful extrapolation from this data can be made. The application of the Bunsen-Roscoe Law to dark adaptation has been mentioned previously. Whether reciprocity holds for intense flashes of light at brief time periods is a moot question

which cannot be answered until considerable additional experimentation has been accomplished. At the present it does not appear that the law can be applied rigorously to the situation in question, an extremely intense flash to which the eye is exposed for a period of 0.1 second or less.

Altogether, there is sufficient information available to permit certain qualitative conclusions notwithstanding the inadequacy of the data required for more specific applications.

The experimental data which can be applied to the problem of rod dark adaptation indicates that the extent and severity of dazzle has been grossly overemphasized.

The generally accepted concept of dazzle implies that it is an absolute, complete, all-encompassing condition. This concept does not take into account the possibility of degrees of dazzle, variations in recovery time introduced thereby, or the role that the luminance of objects viewed plays in the recovery of useful vision. Proper consideration has not been given to the fact that the duration of loss of visual acuity following dazzle is not at all invariable and depends critically upon the nature of the visual task to which the individual returns after being dazzled. That dazzle is not a state of complete loss of vision is evidenced by the various means used in overcoming loss of visual acuity caused by dazzle. The most simple of these and the most readily apparent, is the practice of lighting the instrument panel of strike aircraft. By this means, it is possible to defeat the problem of returning to the state of dark adaptation by permitting the individual to employ mesopic or even photopic vision in his visual task, depending upon the level of illumination provided.

From Figure 1.4 it is seen that immediate recovery of useful vision is proportional to target illumination. It is for this reason, among others, that the problem of dazzle in daylight is not significant. Under daylight conditions an individual exposed to the flash from a nuclear detonation returns to visual tasks under conditions of relatively high illumination.

Only in the case of a moonless, overcast night is it necessary for the individual to become completely dark-adapted before useful vision is regained. As long as there is any degree of illumination on the target above this minimum, the return of effective vision is more rapid and dark adaptation to the degree required is not delayed to the same extent as under the more rigorous conditions of the moonless night. Under conditions of bright moonlight, such as exist with a full moon, it is not necessary for the eye to fully adapt to the level of rod vision. Recovery of mesopic vision is sufficient with its consequent shorter time period for adaptation.

So long as the conditions under which the soldier or airman exist permit the use of additional illumination, the problem of dazzle can be solved by the simple expedient of adding light, thereby reverting to foveal vision and taking advantage of the shorter adaptation times typical of this function.

The worst situation to be considered is that in which the individual on a moonless, overcast night is suddenly dazzled by the flash of a nuclear weapon in his forward field of vision. He goes abruptly from complete dark adaptation to a state of at least partial light adaptation, to be suddenly returned to the original condition of almost complete lack of external illumination. Under this set of circumstances he is required to completely dark adapt again if he must detect form and movement of vehicles or other individuals. This is the most severely limiting case which can be assumed. Return of useful vision in this situation will be delayed and it can be anticipated that combat effectiveness may be lost briefly and decreased for periods up to 30 minutes, after which full dark adaptation should exist. Here again the problem can be defeated, while

avoiding the issue of absolute loss of effectiveness under the worst possible conditions, by the simple expedient of applying illumination to the environment. The use of flares, star shells, searchlights or other light sources will furnish adequate illumination to permit rapid return of vision for most tasks, as the increase in illumination favors mesopic or even foveal vision with a consequently shorter adaptation time.

Chapter 5

CONCLUSIONS and RECOMMENDATIONS

5.1 CONCLUSIONS

There is no significant dazzle effect from fractional kiloton (1-ton to 5-ton) nuclear bursts on personnel at approximately 1 mile from ground zero under daytime conditions when observers are looking more than 90 degrees away from line of sight to the burst.

Loss of combat effectiveness as a consequence of dazzle will not constitute a hazard for personnel during daylight. During the hours of darkness, dazzle will constitute a somewhat greater hazard but still will not be of overriding significance.

Testing to date has been inadequate to evaluate quantitatively the dazzle effect from the spectrum of tactical yield weapons during darkness, partial daylight, and full daylight.

5.2 RECOMMENDATIONS

The first two conclusions listed above should be accepted as guidance in the formulation of tactical doctrine and for the purpose of instruction at appropriate service schools.

The terms "dazzle effect" and "after image" as defined and discussed in Chapter 1 should be adopted, and the term "flash blindness" eliminated from military terminology.

Further tests should be conducted to determine the dazzle effect at varying distances from other tactical yields during darkness, partial daylight, and full daylight.

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